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WATER SOFTENING PRACTICE¹

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During the last year, the writer has had occasion to investigate water softening practice in connection with the development of two water supplies. A considerable amount of data was collected and tabulated, particularly as regards municipal water softening plants. Since these data may be of interest and some service to water works men, they are presented herewith. It is largely a review of present day practice in water softening as applied to municipal supplies and includes a few memoranda on the characteristics of hard waters. Certain special points are emphasized in the light of experience after a number of years of operation of municipal water softening plants.

Water softening should be a subject of special interest to water works men in Illinois and throughout the middle west, where hard well water supplies are so frequently used. Some statistics of Illinois water supplies showing the number of supplies from different sources are therefore of interest. From the McGraw-Hill Water Works Directory, 1915, it appears that in Illinois there are 214 well water supplies of which 72 are from wells less than 100 feet deep, the balance ranging in depth up to more than 2000 feet. Seventy-two supplies are from surface waters, of which twenty are taken from Lake Michigan. Of these supplies, twenty-one surface waters are filtered and two only are softened, those at Freeport and Hinsdale. The plant at Hinsdale is the most recent, having gone into operation in the summer of 1915. The plant at Freeport is more of an iron removal plant than a softening plant.

The desirability of water softening does not depend on sanitary grounds so much as on economic grounds. Within ordinary limits, the hardness of water has little effect upon the public health. However, for both industrial and household uses, hard water is costly. In particular the quality of a municipal water supply for industrial purposes assumes importance where towns are competing for the

¹ Read before the Illinois Section of the American Water Works Association, October 19, 1915.

location of industrial plants. Some towns now depend upon railroad shops and roundhouses or large manufacturing plants for considerable portions of their population. The progressive city with an ample soft water supply will grow while others will stand still.

There is, however, a more direct economic aspect. For certain conditions, depending upon the hardness of the water, the size of the supply and other local items, a town will save money by softening its water. The relation between the cost of softening water and the financial saving which results is very direct, depending upon the character of the water, the size of the plant and the general efficiency of operation. At St. Louis it is estimated that the saving from soap alone amounts to \$496 against a total cost of purification amounting to \$424 per day.

Hard waters are objectionable in many ways. For domestic use they require larger quantities of soap, they are unsatisfactory for washing, have an annoying effect on the skin and increase the plumbing bill. For boiler use, they cause trouble by forming scale in the boilers, cause interruption in service, shorten the life of boilers and fire boxes, and increase the fuel bill. In certain special industrial processes, hard waters are considerably less satisfactory than soft waters. It is likely, therefore, that increasing competition for industrial growth and rising standards for domestic water supplies will lead to a substantial growth of water softening.

HARD WATER

Rain water, which is initially pure and soft, acquires mineral constituents as it percolates through the soil. Some of the minerals are dissolved by the water and others are held in solution by free and half bound carbonic acid (CO_2) in the water. Carbonic acid, or carbon dioxide, is taken up by the water as it falls through the air and from decaying vegetable matter in the soil. It occurs in water in the free state or in the bicarbonate or carbonate form. All of these forms include substances soluble in water. The bicarbonate form refers to the carbonates held in solution by an equivalent quantity of the carbonic acid, such for instance as calcium bicarbonate ($\text{CaCO}_3\text{H}_2\text{CO}_3$). The carbonates of calcium and magnesia are thus held in solution by conversion into the bicarbonate form. The carbonate form is represented by sodium and potassium carbonates which are directly soluble in water.

The mineral content of waters, therefore, depends upon the character of the soils and rocks through which the water has percolated before it is tapped as a source of supply. Igneous rock formations contain a comparatively large proportion of the metals of the alkalis such as sodium and potassium. Secondary rocks formed by sedimentation, on the other hand, contain a larger proportion of the alkaline earths, such as calcium and magnesium. Among these secondary formations are the limestones, dolomites, sandstones, shale, gypsum, glacial deposits, etc.

Iron occurs quite generally in both primary and secondary formations and frequently in gravels and sands. Its most common form is hematite (Fe_2O_3). Water, which has given up its oxygen content to decaying organic matter in the soil, will reduce the iron from the ferric to the ferrous oxide (FeO). Carbonic acid in the water combines with the ferrous oxide to form ferrous bicarbonate ($\text{Fe}(\text{HCO}_3)_2$) which is soluble in water. Iron in water causes discoloration, and in large quantities is objectionable.

Salt and gypsum occur in large deposits not quite so universally distributed as iron. Water passing through or over these deposits takes up the chlorides and sulphates of sodium, calcium and magnesium, all of which are soluble in water.

From these and similar sources, soft rain water is converted into more or less hard water. Obviously hard waters are chiefly derived from deep and shallow wells, although waters from lakes and rivers often contain a considerable hardness.

MINERAL CONSTITUENTS

There are thus a large number of mineral constituents of water. The principal ones which are dissolved by the water itself are the following:

1. Calcium sulphate, sometimes called gypsum, or plaster of paris (CaSO_4).
2. Calcium chloride (CaCl_2).
3. Magnesium sulphate, sometimes called Epsom salts (MgSO_4).
4. Magnesium chloride (MgCl_2).
5. Sodium sulphate, sometimes called glauber salts (Na_2SO_4).
6. Sodium chloride, or common salt (NaCl).
7. Sodium carbonate or washing soda (Na_2O_3).
8. Small quantities of the nitrates of sodium, magnesium and calcium.

In addition, water will dissolve some organic matter and other impurities.

Among the constituents which are held in solution by water containing carbonic acid are the following:

1. Calcium carbonate, sometimes called chalk or marble (CaCO_3).
2. Magnesium carbonate (MgCO_3).
3. Ferrous iron oxide (FeO).
4. Aluminum, which is generally dissolved in very small amounts.

In solution these constituents occur in the bicarbonate form, as already noted. The iron is dissolved by a reduction process in water which is deficient in oxygen.

In addition to these principal mineral constituents, waters may contain sulphuric acid, tannic and acetic acids, hydrogen sulphide gas, suspended matter, oil and other impurities.

TERMINOLOGY

For convenience in studying chemical analyses and reactions, and in the use of literature on water softening, some of the more frequently used terms are described.

1. *Total hardness.* This term is used to indicate the quantity of certain soluble mineral constituents consisting chiefly of the salts of calcium and magnesium. It is generally measured by the soap consuming power of the water. When sodium or potassium soaps are added to hard water, the soap is decomposed and insoluble soaps of lime and magnesium are formed. These form the unsightly scum on the sides of containing vessels. Until the insoluble soaps are precipitated, no lather will form. Thus, hard waters require the use of more soap for successful washing. In precise terms, total hardness, as generally determined, means the soap consuming properties of the water. Both carbonates and sulphates are included in this term.

2. *Temporary hardness.* As already noted, the solubility of calcium and magnesium carbonates depends upon the presence of carbonic acid. If the carbonic acid is driven off by boiling the water, the bicarbonates revert to the carbonate form and are precipitated. It should be noted that the precipitation will not be complete and portions of the carbonates of calcium and magnesium will remain dissolved even after prolonged boiling. By boiling, therefore, the hardness of the water is reduced. The hardness thus removed is spoken of as the temporary hardness.

3. *Permanent hardness.* The mineral constituents which remain in the water after prolonged boiling, form the permanent hardness. This hardness is due largely to the chlorides and sulphates of lime and magnesium and to the carbonates of these bases remaining in solution.

4. *Alkalinity.* Alkalinity in water is caused by the presence of certain salts of the alkalis and alkaline earths. It is measured principally by the carbonates of sodium and potassium and the carbonates and bicarbonates of calcium and magnesium. The hydrates of these salts also add to the alkalinity, producing what is termed caustic alkalinity. The alkalinity differs from the temporary hardness, by measuring the amount of hydroxyl ions present while the hardness is limited to the salts having a soap consuming power. It will ordinarily run higher than the temporary or "carbonate" hardness because the hydrates are included, although the difference is not generally great.

5. *Carbonic acid* (CO_2). That portion of the carbon dioxide which is in chemical combination with the carbonates of calcium, magnesium, iron and alumina to form bicarbonates is called half-bound. Any excess in the water over this amount, and over that present strictly as carbonate, is called free carbonic acid. Of the carbonic acid in the bicarbonates, one-half is half-bound, the other half being true carbonates.

Free carbonic acid has a corrosive action on service pipes, particularly lead and galvanized iron. The corrosive action is stronger in soft water than in hard because calcium carbonate forms a protective coating on the inside surface of the pipe.

6. *Incrustants.* This term is synonymous with permanent hardness. It includes the sulphates, chlorides and nitrates of lime and magnesium. The solubility of these salts is not affected by boiling the water. But when a water is evaporated, as in steam boilers, the concentration increases until the water can no longer hold the salts in solution and a hard incrustation or scale is formed. At a temperature of 70° F. one part of calcium sulphate is soluble in 390 parts of water. Some authorities state that the solubility of calcium sulphate becomes less as the temperature increases, but it is generally agreed that concentration is required for its precipitation.

7. *Acidity.* Some waters contain free acids, which give the water an acid reaction. These acids include free sulphuric acid from industrial pollution and from the sulphates of iron and alumi-

num. The acidity can be determined by titration against a standard sodium carbonate solution, the acidity being expressed in terms of equivalent sodium carbonate required to neutralize the acidity.

ACTION OF HARD WATERS

The action or effect of hard waters depends upon the service and also upon the character of the water. The more important actions of hard waters are described below.

Boiler Scale

When the mineral constituents of water are precipitated from solution within a boiler, a scale is formed which will be hard or soft, depending upon the composition of the water.

Calcium carbonate, when present alone, is generally deposited as a soft scale. Its precipitation begins at a temperature of about 130° F., so that it will be deposited in feed water heaters, condensers and feed water lines as well as in the boiler. With other constituents, it often combines to form a hard scale.

Magnesium carbonate though more soluble than calcium carbonate, is not entirely precipitated except by the concentration of the water. It is, therefore, deposited chiefly in the boiler as a soft mud or scale. Parts of it which are deposited on the hot surfaces of a boiler are changed by the heat into magnesium hydrate or oxide, both of which form hard scales.

Calcium sulphate forms a very hard scale which results from the combined effect of heat and concentration, and is found only in boilers. Magnesium sulphate is not a scale forming constituent because it is very soluble in hot water. But when calcium carbonate is also present in the water, a reaction takes place which results in the formation of magnesium hydrate and calcium sulphate, both forming exceptionally hard scales.

Iron and aluminum oxides form scale by precipitation from the soluble bicarbonate form, just as calcium carbonate is precipitated from the bicarbonate. However, on heating they are changed to the oxide form.

Silica, suspended matter and organic matter add to the thickness of scales by becoming cemented with other scale forming constituents.

Foaming

Foaming of water in steam boilers is chiefly a mechanical action produced by interference with the bursting of the steam bubbles so that small drops of water are carried off with the steam. The principal cause is the presence of suspended matter in the water which produces the interference by forming a surface scum on the water. The same action results when calcium and magnesium carbonate are precipitated in a light flaky condition. The foaming is more active if the water contains comparatively large amounts of soluble salts or organic matter. The amount of foaming also depends upon the type of boiler and the methods of operation. Foaming will increase as the concentration of the water increases in the boiler.

Corrosion

There are two forms of corrosion. One occurs in the cold in pipes. It is produced by the presence of hydrogen ions and dissolved oxygen in the water. All acids have a tendency to form hydrogen ions by dissociation. They attack metallic iron and dissolve it in the ferrous form (FeO). This is then oxidized by the oxygen to the ferric form (Fe_2O_3) and appears as iron rust. This action takes place to some extent with pure water and is not strictly associated with water softening problems.

The second form of corrosion takes place in boilers. The most active element in this form of corrosion is sulphuric acid. This attacks the boiler iron, forming soluble iron sulphate. The heat in the boiler splits this up into iron hydrate and free sulphuric acid, so that the process continues indefinitely. Other free acids as well as the sulphates of iron and aluminum are corrosive in this same way.

Carbonic acid also has a corrosive action which generally takes the form of pitting. This gas is set free from the bicarbonates by boiling and under a combined action with the heat, moisture and oxygen present in a boiler pits the metal wherever it has attached itself to the inner surfaces of the boiler.

The chloride constituents also are corrosive. Magnesium chloride, for instance, under boiler pressure, is decomposed into magnesium hydrate and hydrochloric acid which attacks the boiler metal to form soluble chloride of iron. It will eat out the metal of stove tanks.

Fatty acids in a boiler, due to the saponification of animal or vegetable oils, used for lubricating for instance, are other causes for active corrosion.

Deposits

Hard waters will form deposits or incrustations in mains, service pipe, valves, meters, etc., causing considerable trouble and work for plumbers. In the softening process, deposits sometimes occur due to incomplete reactions at the softening plant. These deposits are largely lime. In a similar way, sand grains in filters become incrustated and deposits may also occur in the filter sand and underdrains. The size of sand grains is thus enlarged and the depth of the filter increased. The action is sometimes prevented by adding carbon dioxide to the softened water.

Soap consumption

The harder the water, the more soap will be required for satisfactory washing. The action of the soap in hard water is really a softening reaction. Experiments by Whipple indicate that with a water containing 200 parts per million of hardness, the average soap will soften about 24 gallons. In other words, this proportion of soap must be added to the water before a lather is formed. This is equivalent to about 20 tons of soap per million gallons of water used. If soap is worth 5 cents per pound, this is equivalent to \$2000 per million gallons. If we assume that only a hundredth part of the water supply is used with soap, the actual saving will be \$20 per million gallons. If the water is harder, the saving will be greater; and if the softening is not complete, the saving will be less. This saving can be balanced against the cost of softening the water. In table 4 it appears that the cost of softening water varies from \$10 per million gallons up to \$30, exclusive of fixed charges, which would add from \$4 to \$5 per million gallons. On soap saving alone, therefore, the cost of softening water is often justified. In addition, other less tangible savings should be included. In communities which use more soap, the saving will be increased.

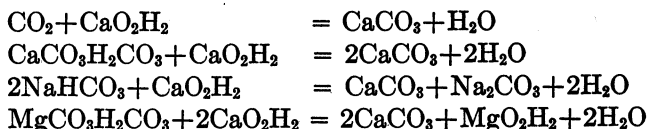
THE SOFTENING PROCESS

General

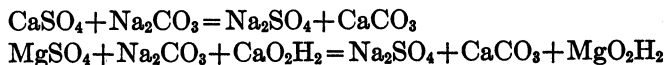
A hard water may be softened by precipitating out the hardening mineral constituents, or by changing them into substances which do not harden the water. The former process is accomplished by the addition of lime (CaO_2H_2) or soda ash (Na_2CO_3) or both. The second process is accomplished by passing water at a proper rate through crystals of an artificial or natural zeolite such as "Permutit."

Reactions

Temporary or carbonate hardness is removed by adding to the water a suitable quantity of lime water. This process was discovered by Clarke in 1841. The lime combines with the free and halfbound carbonic acid and forms a precipitate of calcium carbonate in the form of a fine granular solid. Not only the lime originally present in the water as bicarbonate is thus precipitated, but also the lime which has been added to the water. The reactions are indicated by the following expressions:



Permanent hardness requires the addition of soda or both soda and lime water for its removal. If the permanent hardness is due to calcium salts, sodium carbonate is sufficient. But if the hardness is due to the presence of magnesium salts, both chemicals must be added. The reactions are indicated by the following expressions:



Of the products of these reactions, calcium carbonate and magnesium hydrate, which appear as precipitates, are removed by sedimentation and filtration. The sodium sulphates and carbonates remain in solution and are harmless in the amounts ordinarily present.

Nature of reactions

The chief product of these reactions is calcium carbonate. This is soluble in water to the extent of about 30 parts per million, so that it is impossible to remove the hardness completely.

The reaction of the lime salts takes place directly. When magnesium carbonate is present, however, the first product is a mixture of carbonates and hydrates of magnesium which are more or less soluble. Sufficient additional lime must be added to form magnesium hydrate as an insoluble gelatinous precipitate.

Time of reactions

The time required for the completion of these reactions is of considerable importance. If the reactions are not completed after-precipitations will occur, causing deposits in filter underdrains, distributing mains and valves, and in service pipes and meters. These deposits often cause considerable inconvenience.

This feature is probably more important in municipal service than in industrial service. In railroad supplies, for instance, the softened water is often stored in tanks before use and its use is largely restricted to engine boilers. Opportunities for troublesome deposits are not so numerous as in municipal water systems. Improvements over the hard raw water often induce superintendents to overlook troubles from after-deposits.

Estimates of the necessary time to allow for the reactions vary from three hours to six days. Most of the stock water softeners, such as are built for industrial and railroad service, provide from three to six hours coagulation and sedimentation based on the rated capacity. Experience at the Oberlin, Ohio, plant indicates that with four days in the settling basins, after-precipitation occurs to a moderate extent. Tests made with a six day period showed practically no after-reactions. This experience and others are given more at length under the caption "Results in Practice."

The time for the reactions depends on the character of the water, the intimacy of the mixture of the chemicals and the water, on the temperature and on other local factors. It is also probable that the reaction is promoted by mechanical agitation. This not only hastens the reaction, but also increases the degree of completeness. This result may be accomplished in closely baffled

mixing basins and in other ways. It appears, also, that the addition of a small amount of a coagulant such as aluminum sulphate causes a greater reduction in the alkalinity of lime treated water than the theoretical reaction would indicate.

Whipple states that the magnesium reaction takes place more rapidly than the calcium reaction. He finds that after-deposits are composed chiefly of calcium carbonate and contain very little magnesium.

All these features are necessary considerations in the design of a water softening plant.

Zeolites

Zeolites are minerals consisting of hydrated silicates of aluminum with alkalis and alkaline earth. A zeolite has the power of exchanging its base for that of another salt.

Permutit, which is manufactured for water softening purposes, is an artificial zeolite. Sodium permutit is a hydrated sodium silicate, the composition of which can be expressed as follows:



It is manufactured by fusing a mixture of feldspar (KAlSi_3O_8) kaolin ($\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$), pearlash (K_2CO_3) and soda, mixed in definite proportions. The product is porous and granular. A manganese permutit can also be prepared for use in removing iron.

Water softening by permutit or other zeolite is very different from the lime and soda process. The apparatus used is similar to a sand filter of the pressure type and can be "cut in" on a main supply line. The zeolite, however, takes the place of the sand in the filter. A typical cross section is shown in figure 1. At the top is a perforated tray holding a layer of gravel or marble chips. Below this is an open space and then the permutit resting on gravel and another perforated platform. The layers of gravel do not act as filters to remove turbidity. Experience with Lake Michigan water at the Union Stock Yards, Chicago, demonstrates the necessity of removing the turbidity from the raw water before softening it.

The calcium and magnesium salts forming the hardness of the water are not precipitated as in the lime-soda treatment, but are converted into sodium salts which are soluble and nonscale forming. After a time the permutit will have exchanged its sodium to an

economic limit, and "regeneration" will be necessary. This is done by passing a solution of common salt (NaCl) through the permutit and reconvertng the calcium and magnesium permutit back to sodium permutit. The regeneration process takes about ten hours, so that the net softening period for one apparatus is 12 to 14 hours per day.

The rate of softening depends, of course, upon the character of the raw water. Hoover and Scott at Columbus report that, with raw water having a total hardness up to 392 parts per million, the

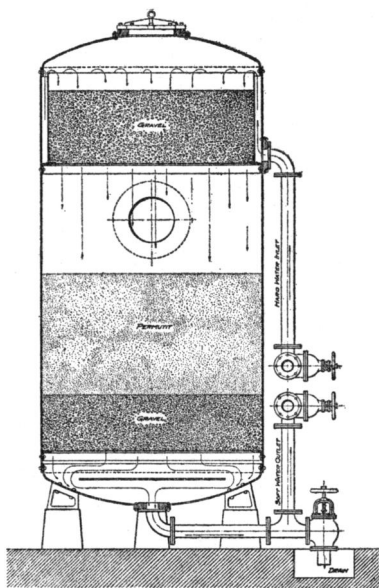


FIG. 1

highest efficient gross rate of filtration was 55,000,000 gallons per acre per day, giving a net rate of about 25,000,000 gallons per acre per day.

By this process a water can be completely softened. Calcium and magnesium can also be nearly completely removed by treatment with lime and soda, if they are added in large excess. But this is impracticable, because the excess of these chemicals in the softened water would generally be objectionable. With permutit, however, the softening reagent is insoluble and a large excess can be used. Hoover and Scott, in their experiments with permutit,

found it advisable to use about 16 times as much permutit as the theoretical quantity.

The experiments made at Columbus tested the applicability of the zeolite process for softening Scioto River water, which has a hardness of about 350 to 400 parts per million. The results are summed by Hoover and Scott as follows:

Advantages

1. It is the only practical process, known to the writers, by which water of zero hardness can be produced on a large scale.
 2. Only one chemical is needed (common salt).
 3. Variations in the hardness of the raw water are automatically taken care of.
- There is no sludge to be removed.

Disadvantages

1. Cost of operation is higher than with lime and soda ash. For waters requiring a large amount of soda ash for softening, the cost of zeolite will compare more favorably.
2. Water to be softened must be perfectly clear, for if it contains any turbidity, the pores of the permutit become clogged.
3. The permutit softened water contains residual sodium bicarbonate, and if used for boiler feed purposes, may cause trouble by foaming.

ILLINOIS WATERS

As already pointed out, a variety of waters are used for public water supplies in Illinois. Analyses of waters typical of several different sources are given in table 1. These analyses, of course, are not applicable to any particular water and do not show variations in the character of the water. The Pottsdam waters seem to have less sulphate and more carbonate hardness than the St. Peters waters, although exceptions have been recorded.

The actual construction of water softening plants has developed not only in industrial service but also to a considerable extent in municipal service. At the present time there are upwards of ten municipal water softening plants in operation in this country. These two kinds of service are often quite different and these differences are interesting.

TABLE 1

Mineral analyses of typical Illinois water supplies—parts per million*

CONSTITUENTS†	LAKE MICHIGAN	SHALLOW WELL 100 FEET DEEP	WELL FROM THE ST. PETERS STRATA	WELL FROM THE POTSDAM STRATA
Sodium nitrate.....	2.3			
Sodium chloride.....	5.9		24.1	8.9
Sodium sulphate.....	4.9	94.8	40.5	13.9
Magnesium sulphate.....	6.8	141.4	75.0	1.5
Magnesium carbonate.....	32.6	31.5		116.5
Calcium carbonate.....	82.1	395.3	70.2	193.4
Calcium sulphate.....			187.0	
Oxide of iron and aluminum.....	3.6		3.8	0.3
Silica.....	4.6	4.2	0.4	10.3
Total solids.....	143.0	700.3	481.3	352.4

* Data from Illinois Geological Survey and Water Survey Reports.

† List of constituents contains only principal salts.

Industrial service

A very large number of softeners have been installed for railroads, laundries and industrial establishments. Many of these have been built by concerns which make a specialty of building and installing water softeners and there are a number of excellent "makes" on the market. Others are installed by the railroads themselves.

The service is generally more direct than municipal service. In railroad service the softened water is stored in a tank and delivered directly to the locomotive boiler. With manufacturing plants, the distribution is somewhat more extended but not so much so as in municipal supplies. In locomotive boilers, the tendency to foam is greater than in stationary boilers. Soap is not used so much in the industries, except laundries. For each of these services, therefore, the treatment should be properly adjusted. A municipal supply which embraces many users, should be carried out with great care.

Municipal service

The design of a water softening plant for this service includes the following principal features:

1. Handling of chemicals.

2. Chemical feed apparatus.
3. Mixing chemicals with raw water.
4. Provision for the chemical reaction (coagulation) and sedimentation.
5. Filtration.
6. Sludge handling.
7. Disposal of waste water.

It is not within the scope of this paper to discuss the design of these features in detail. However, a few interesting notes are given which have developed from the information received.

TABLE 2
Operating data, municipal water softening plants, October, 1915

PLANT	AVERAGE HARDNESS OF RAW WATER	POPULATION 1910	QUANTITIES		PERIOD FOR REACTION AND SETTLING, BASED ON ACTUAL QUANTITIES	REMARKS ON AFTER PRECIPITATION
			Rated	Actual		
	<i>p. p. m.</i>		<i>m. g. d.</i>	<i>m. g. d.</i>	<i>hours</i>	
St. Louis, Mo.....	170	687,029	160	100	40-60*	No trouble since filters have been in operation.
Columbus, O.....	300	181,511	30	18.4	20.6	
Grand Rapids, Mich....	235	112,171	20	14.	3½ to 3	Requires careful operation and mixing. Alum used.
McKeesport, Pa.....	100-600	42,694	10	3.6	7½ to 20	Incrustation of filter sand. No deposits in mains.
Owensboro, Ky.....	300	16,011	3	1.5	48	Some precipitate. Not enough to cause trouble.
Oberlin, O.....	300	4,365	0.75	0.28	48	Incrustation of filter sand.
Daytona, Fla.....	360	3,082	0.30	0.17	4 to 18	A little trouble reported, especially when settling period is short.
Hinsdale, Ill.....	360	2,451	1.00	0.30	20 to 40	
Port Tampa, Fla.....	640	1,343	0.24		12†	

* Depends on basins in service.

† Based on rated capacity.

General statistics of municipal plants now in operation are shown in tables 2 to 4.

1. *Chemical handling.* In a number of small plants it has been found that hydrated lime in bags is more convenient to handle and store than lump lime in barrels or in bulk. At Columbus it was found that lime stored in bags for a long time became air slaked and lost strength.

Most of the chemical tanks are fitted with mechanical agitators. At Hinsdale, where slaked lime is used, one tank serves for both lime and soda solutions. There is a motor driven agitator in the tank. This is a quite general practice.

2. *Chemical feed.* A number of devices for controlling the chemical feed are available. At Hinsdale the raw water is pumped at a constant rate and the control consists in the discharge of a definite amount of the chemicals while the pumps are running. Variations in the flow are taken up in the water storage tanks. The control

TABLE 3
First cost of municipal plants in America, October, 1915

PLANT	DATE OF ERECTION	POPULATION 1910	QUANTITIES		COST OF CONSTRUCTION		REMARKS
			Rated	Actual	Total	Per million gallons rated capacity	
			<i>m. g. d.</i>	<i>m. g. d.</i>			
St. Louis, Mo.....	1915	687,029	160	100	\$1,495,000	\$9,344	Cost approximate*
Columbus, O.....	1906	181,511	30	18.4	590,780	19,693	First-class construction
Grand Rapids, Mich...	1910	112,171	20	14.0	449,569	22,478	First-class construction
McKeesport, Pa.....	1908	42,694	10	3.6	250,000	25,000	First-class construction
Owensboro, Ky.....	1906	16,011	3	1.5	30,000	10,000	Excelsior filter
Oberlin, O.....	1903	4,365	0.75	0.28	12,000	13,300	Pressure filter
Daytona, Fla.....		3,082	0.30	0.17	4,304	14,347	No filters
Hinsdale, Ill.....	1915	2,451	1.0	0.30	18,000	18,000	Filters 18 inches deep
Port Tampa, Fla.....	1914	1,343	0.24		7,000	29,100	No filters

* Existing work also used, but not included in figures.

apparatus consists of a floating orifice submerged below the surface of the chemical solution at the proper depth to take off the chemicals at the desired rate. A control tank stands near the chemical solution tank. This tank is filled by raw water which flows into it while the main pumps are running. The rate of filling this tank is controlled by a divided weir. There is a float in the tank which is connected with the floating arm in the chemical solution tank by a wire and pulleys. As the control tank fills the floating orifice is lowered, so that the rate of applying the chemical is proportioned at will by regulating the rate of filling of the control tank. When

the control tank is full, the contained water is wasted to a sewer. The effluent from the chemical solution tank is pumped to the raw water at the top of the settling tank.

In another apparatus, the chemical solutions are pumped from the tanks to a chemical regulator above. The regulator contains a cutoff weir which divides the flow of chemical, one part flowing to the raw water and the other returning to the chemical solution tanks. The position of this weir is determined by a float in a control basin located below the regulator box. The raw water passes

TABLE 4

Annual cost of operation and chemicals used, municipal water softening plants, October, 1915

PLANT	POPULATION 1910	ACTUAL QUANTITY, MILLIONS OF GALLONS PER YEAR	AVERAGE HARDNESS OF RAW WATER	CHEMICALS USED—POUNDS PER MILLION GALLONS					OPERATORS REQUIRED, TOTAL	COST OF OPERATION PER MILLION GALLONS
				Lime	Soda ash	Iron	Alum	Hypo		
St. Louis, Mo.....	687,029	34,656	<i>p. p. m.</i> 170	800		415		1.6	35	\$4.56†
Columbus, O.....	181,511	6,716	300	1384	1054		260	4		17.46
Grand Rapids, Mich.....	112,171	4,506	235	1250			120		16	11.34
McKeesport, Pa.....	42,694	1,314	100-600	100 to 3500	100 to 6000	50 to 200	75 to 400			27.57
Owensboro, Ky.....	16,011	547	300	2000	75			1	2	10.05
Oberlin, O.....	4,365	102	300	2045	735				1*	13.49
Daytona, Fla.....	3,082	62	360	2910	250				1*	23.80
Hinsdale, Ill.....	2,451	100	360	4091	1368		small amount		1*	30.00

* Part time of one man.

† Does not include pumping.

through the control basin and into the mixing basins over "Sutro" weirs. These weirs are so constructed that the quantity of water flowing over them is directly proportional to the head. This apparatus, therefore, takes care of a variable flow of raw water. At the Owensboro, Kentucky, plant where this control apparatus is used, the lime and soda solutions are made up in one tank.

In another device, a constant head of chemical solution is maintained in a control box by pumping an excess of solution and providing the box with an overflow. The outlet is through an orifice at the bottom in which a tapered plug moves. Thus the quantity of

solution depends upon the position of the plug and this is determined by the quantity of water flowing through a Venturi meter.

At other plants small orifice feed boxes fitted with ball-cocks are used. The type for each condition depends upon the size of the plant, the cost and other local factors.

3. Mixing basins. Mixing basins, sometimes spoken of as softening tanks, are practically always provided. Two types are generally used. One promotes the mixture of the chemical solutions and raw water by mechanical agitation and the other by baffling.

At the Owensboro, Kentucky, plant there are four mixing basins, each containing four sets of agitators. The period in these four basins is one hour. At Daytona, Florida, the mixing is promoted by compressed air which is allowed to bubble through the mixture of chemicals and raw water.

At St. Louis, Columbus, Grand Rapids and McKeesport baffled mixing basins are used, providing mixing periods of about one hour on the rated capacity.

Some of the manufactured softeners provide mechanical agitation for a few minutes near the top of the inlet to the softening tank.

4. Provision for reaction and settling. As already indicated, municipal water softening plants have been designed along somewhat more liberal lines than manufactured softeners, especially as regards the time allowance for the reactions of the chemicals and for settling. The period provided in a number of operating plants is shown in table 2. The general experience indicates that troubles with after deposits grow less as the time allowance increases.

Ample provision for settling is undoubtedly costly and for this reason the design of the coagulating and settling basins should be made with great care. It frequently happens that the actual period or flowing through time is considerably less than the displacement period. This difference should be reduced as far as possible by proper design and operation. In cold weather, this feature assumes greater importance.

The point is illustrated by results of analyses made at the Oberlin, Ohio, plant by the state board of health (table 5).

5. Filtration. Filters are generally built with water softening plants to remove the precipitated salts and also the turbidity. Frequently they would be required for clarification and bacterial removal even if there were no softening. At Daytona, Florida, however, no filters are used. At Owensboro, Kentucky, the filters

are made of excelsior. Mechanical filters of both the gravity and pressure type are used, the former being used more extensively in the larger plants.

6. *Sludge handling.* In water softening a large amount of sludge is produced, the handling of which adds to the cost of operation. A number of methods for removing this sludge from the settling basins have been devised. In very large basins, after draining the sludge is discharged into a sewer by flushing with a hose and by hand scraping.

At Owensboro, Kentucky, the settling basins are fitted with a series of pipes resting on the bottom of the basins. This sludge removal system is divided into three sections in each tank, each

TABLE 5

Average results of analyses of raw and softened water, especially illustrating progression of softening—parts per million

SOURCE	TOTAL HARDNESS			
	A	B	C	D
Raw water.....	240	235	239	271
Outlet first basin.....	146	172	108	123
Outlet second basin.....	100	120	112	101
Outlet filters.....	83	104	99	86
Service mains.....	51	74	81	74

A—September 11, 1906.

C—March 19–20, 1907.

B—January 15–18, 1907.

D—August 20–21, 1907.

section being operated by a quick opening gate valve. The pipes extending across the basin are spaced about 3 feet apart and are perforated at 3-foot intervals. The tanks at Oberlin, Ohio, are also fitted with a so-called sludge removal system made up of 3-inch cast iron pipe, connecting to 6-inch cast iron main outlet pipes.

The manufactured softeners are fitted with a variety of devices for handling the sludge. At Hinsdale the device consists in a pipe set several inches above the bottom of the softening tank. This pipe is slotted along its under side. It can be revolved slowly so as to cover the entire tank bottom. At the top and center, it connects to an outlet pipe. The discharge is thus by the pressure of the overlying water as in sludge removal from an Imhoff tank. In other types, the bottom of the softening tank is built up of a large

number of small inverted cones, each connecting to a branch outlet pipe.

7. *Waste water.* The disposal of the waste water containing the sludge and the material washed from the filters is important. The lime salts in the sludge are apt to cause unsightly deposits in small streams. The volume of sludge is also comparatively large, which makes its disposal more difficult.

RESULTS IN PRACTICE

It is interesting to record a few of the benefits which have resulted to cities where water softening plants have been built. The following items are noted from a number of letters received from water works superintendents.

1. Soft water systems and double systems of plumbing no longer required.
2. Softening processes at the laundries discontinued.
3. Coal saved in water works pumping stations and in other power plants.
4. More palatable tea and coffee.
5. No stoppage of "stove backs."
6. Increased satisfaction with the water in domestic service.
7. Lower plumbing bills.
8. A large saving in soap.
9. Less trouble with boiler operation from scale formation.
10. A better water for ice making.

SUMMARY

1. As competition between municipalities for industrial establishments increases and as general water supply standards grow, the softening of municipal water supplies is likely to become a more general practice. This is particularly true in the middle west.

2. Hard waters have various characteristics and each water varies in quality from time to time, even when the water is drawn from a well.

3. As a whole, the chemistry of water softening is fairly complete, but there are still a number of undetermined points about which more information is desirable. Such, for instance, are the questions of foaming and of after-deposits.

4. There are now in operation a number of municipal water softening plants, from which a considerable experience is available. Careful design is required for each locality, with somewhat more liberal allowances in capacity than the manufactured softeners provide.

5. In many instances, even in small towns, the annual savings due to water softening will more than offset the cost.

In conclusion, the author wishes to acknowledge the kind assistance of Dr. Arthur Lederer, Mr. Robert A. Allton, and the various water works superintendents of the cities mentioned for information kindly sent to him.

DISCUSSION

MR. EDWARD BARTOW: In 1910 the speaker presented an article entitled "Water Softening for Municipalities" before the Indiana Water Supply Association. In the paper municipal water softening was advocated. It was stated that it could be done with slightly increased cost wherever it was necessary to filter a water supply to remove impurities; but that it would be a more expensive process to soften a well water which was hygienically pure and clear and does not require filtration.

The Hinsdale plant is the first plant constructed in Illinois, and it is to be hoped that it will be so successful that it will be a forerunner of other plants. Illinois waters are quite hard and there is a great field for water softening throughout the state.

An excellent example of saving by water softening has been brought to our attention. At the textile factory at Champaign, Illinois, the water was formerly softened by soap. The practice was to add 6 pounds of soap, costing 8 cents per pound to 250 gallons of water. The lime soap formed was removed by skimming and a bleaching mixture added to the water. When permutit softened water was used the 24 pounds of soap per 1000 gallons were saved and also 12 pounds less soap were needed for the bleaching mixture. The total saving in soap was, therefore, 36 pounds, or about \$3 per 1000 gallons. Whether the water is softened by the zeolite or by the lime soda process the saving of soap is the same for each part per million of hardness removed.